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Temperature Dependence of an MR-Visible Injectable Fricke Hydrogel Dosimeter for MR-Guided Radiation Therapy

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ABSTRACT

Current in vivo dosimetry methods are largely limited to surface or intracavitary measurements and cannot directly measure dose within deep tumors or nearby critical structures. An MR-visible injectable Fricke gel dosimeter has been developed as a proof of concept for internal dose verification during MR-guided radiation therapy. Because of the intended eventual application, it is important to understand how body temperature affects the response of such dosimeters. In this study, the dose response of the gel was evaluated at room temperature and 37°C using quantitative R_1 mapping on a 1.5 T MR-Linac. The dosimeter maintained an linear response under both temperature conditions; however, the response at 37°C was lower at room temperature. These results show that temperature affects the dosimeter response and should be considered when calibrating the gel for future in vivo applications.

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INTRODUCTION

- We have developed a self-forming Fricke gel as a proof-of-concept for an injectable in vivo dosimeter for MRgRT.
- The gel dose response can be measured by MRI because of changes in the longitudinal relaxation rate **($R_1 = 1/T_1$)**, which increases as radiation causes oxidation of ferrous ions.
- Since this dosimeter is intended for eventual use inside the body, its response at 37°C must be understood before it can be used for accurate dose measurements.

Study Objective: Determine how temperature affects the dose response of an MR-visible injectable Fricke gel dosimeter.

METHODS AND MATERIALS

Experimental Setup

- All imaging and irradiation were performed on a 1.5 T Elekta Unity MR-Linac.
- Four injectable Fricke gel dosimeter cuvettes from the same batch were used.
- Two cuvettes were maintained at 37°C and two were maintained at room temperature.
- A custom thermally insulated phantom and MR-safe positioning device were used to maintain consistent geometry throughout the study.

Irradiation & MRI

- Measurements were performed over five independent sessions.
- Each cuvette was irradiated with a 15 × 15 cm² open field at dose levels of 0, 150, 300, 450, 600, 750, and 900 cGy.
- After each irradiation, MRI images were acquired using a variable flip angle sequence with 7° and 36° flip angles.
- Quantitative R_1 maps were generated from the MRI data using MATLAB.

Data Analysis

- A 0.5 cm² ROI was selected from the center of each cuvette.
- Mean R_1 values were measured at every dose level.
- R_1 versus dose was fit using linear regression.
- The slope of each fitted line was used to compare dose sensitivity between room temperature and 37°C conditions.

(a) Thermally insulated phantom

(b) Cuvette holder

(c) MR-safe positioning holder

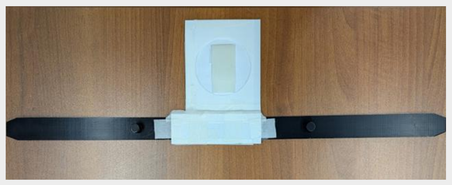

Figure 1. Experimental setup used for MR imaging and irradiation.

RESULTS

Baseline Dose Response

- Figure 2 shows the baseline room-temperature dose response of the injectable Fricke gel dosimeter.
- All four cuvettes showed a linear increase in R_1 with increasing dose and showed agreement in slope between samples.
- These measurements established the reference dose response for comparison with the temperature study.

Temperature Dependence

- Figure 3 compares the average R_1 response for room-temperature and 37°C conditions over five measurement sessions.
- Both temperature groups showed a linear increase in R_1 with increasing dose.
- The **37°C** samples showed a lower dose response than the room-temperature samples.
- The average slope at 37°C was **1.78×10^{-4} ΔR_1 (s^{-1})/cGy**, compared to **2.77×10^{-4} ΔR_1 (s^{-1})/cGy** at room temperature.
- This corresponds to an approximately **33% reduction** in dose sensitivity at body temperature.
- The observed trend was consistent across all five measurement sessions.

The injectable Fricke gel dosimeter maintained a linear dose response at both temperatures, but sensitivity decreased by approximately 33% at 37°C compared with room temperature.

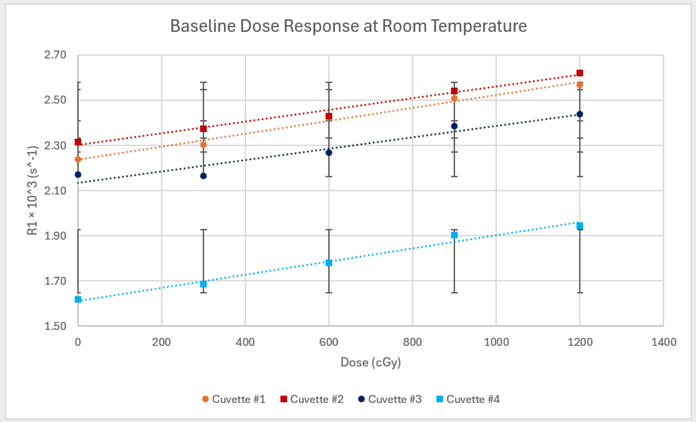

Figure 2. Baseline dose response of the injectable Fricke gel dosimeter at room temperature, showing the relationship between R_1 and delivered dose for all four cuvettes.

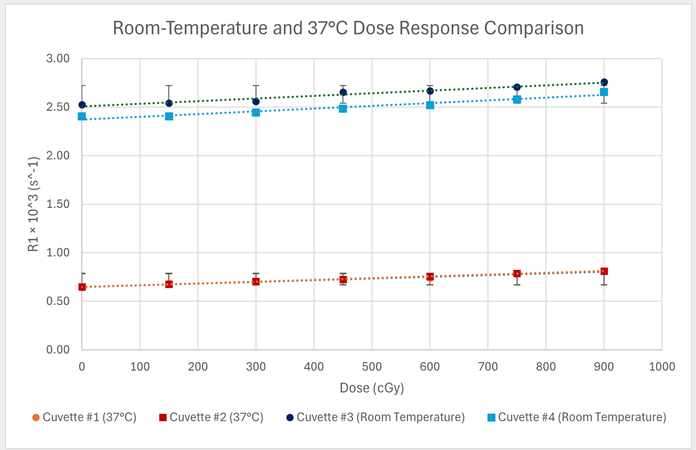

Figure 3. Comparison of the dose response of the injectable Fricke gel dosimeter at room temperature and 37°C using the average R_1 values from five measurement sessions.

DISCUSSION

- The injectable Fricke gel dosimeter maintained a linear dose response under both room temperature and 37°C conditions.
- Although the dosimeter remained responsive to radiation, the lower slope at 37°C indicates reduced sensitivity at body temperature.
- The consistent trend observed across all five measurement sessions suggests that the difference in response is systematic rather than the result of random measurement variation.
- These findings show that temperature should be considered when calibrating the dosimeter for future in vivo applications.

CONCLUSIONS

- An MR-visible injectable Fricke gel dosimeter was evaluated at room temperature and 37°C using quantitative R_1 mapping.
- The dosimeter maintained a measurable, linear dose response under both temperature conditions.
- A reduction of about 33% in dose sensitivity was observed at 37°C.
- These results shows that the dosimeter should be calibrated at body temperature or corrected for temperature effects before future in vivo use.

FUTURE WORK

- Develop temperature-specific calibration methods.
- Confirm dose response and temperature dependence in tissue and animal models

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